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Phosphate Rock

UNITED STATES DEPARTMENT OF THE INTERIOR

The statistical data in this volume represents the most comprehensive, verified, domestic and international coverage for 1987 at the time the volume went to press. More recent information can be found in the monthly Phosphate Rock Mineral Industry Surveys obtainable from Publications Distribution, Bureau of Mines, Box 18070, Cochrans Mill Road, Pittsburgh, PA 15236.

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This publication is a chapter from the current Bureau of Mines Minerals Yearbook, comprising *Volume I, Metals and Minerals; Volume II, Area Reports: Domestic; Volume III, Area Reports: International.* The separate volumes of the Yearbook are sold by the Superintendent of Documents, Washington, D.C. 20402.

Phosphate Rock

By William F. Stowasser[1]

The precipitous decline in phosphate rock production in 1986 from 50.8 million tons[r] to 40.3 million tons appears to have stabilized in 1987 when 41.0 million tons was produced. The result of the slight increase in production in 1987 was a further decline in both domestic and export selling prices in an intensely competitive international market. Exports of phosphoric acid, ammonium phosphates, and superphosphate were the principal markets for the phosphate industry, but selling prices at times throughout the year did not cover production costs.

Phosphate rock consumption increased about 4%, a reflection of the depressed domestic and international markets for agricultural products and phosphate fertilizers. In the United States, acreage reduction programs remained in place, and Government subsidies supported the agricultural sector at a level equivalent to that of 1986.

Table 1.—Salient phosphate rock statistics[1]

(Thousand metric tons and thousand dollars unless otherwise specified)

	1983	1984	1985	1986[r]	1987
United States:					
Mine production (crude ore)	125,691	163,012	175,227	135,683	148,426
Marketable production	42,573	49,197	50,835	40,320	40,954
P_2O_5 content	13,088	14,889	[r]15,634	12,248	12,470
Value	$1,021,095	$1,182,244	[2]$1,235,800	[2]$897,131	[2]$793,280
Average per metric ton	[3]$23.98	[3]$24.03	[4]$24.31	[4]$22.25	[4]$19.37
Sold or used by producers[5]	46,839	53,277	46,634	41,776	43,673
P_2O_5 content	14,336	16,244	14,363	12,750	13,286
Value	$1,122,966	$1,278,356	[2]$1,133,675	[2]$929,621	[2]$845,812
Average per metric ton[4 6]	$23.97	$23.99	$24.31	$22.25	$19.37
Exports[7]	12,010	11,528	9,136	7,848	8,454
P_2O_5 content	3,839	3,646	2,931	2,521	2,737
Value	$327,345	$324,784	[2]$263,631	$211,701	[2]$194,691
Average per metric ton[4]	$27.26	$28.17	$28.86	$26.97	$23.03
Imports for consumption	9	[8]9	[8]34	528	464
C.i.f. value	$376	$274	$1,747	$25,435	$22,134
Average per metric ton	$42.69	$31.71	[9]$51.54	[9]$48.18	$47.70
Consumption[10]	34,838	41,758	37,532	34,456	35,683
Stocks, Dec. 31: Producers'	[r]4,500	11,897	15,534	13,277	10,884
World: Production	[r]140,889	[r]151,568	148,606	[p]138,740	[e]145,148

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.
[2]The total value is based on a weighted value.
[3]Arithmetic average of sold or used values.
[4]Computer-calculated average value based on the weighted sold or used value.
[5]Includes domestic sales and exports.
[6]Weighted average of sold or used values.
[7]Exports reported to the Bureau of Mines by companies.
[8]Bureau of the Census data, excluding reported Canadian and Israeli imports.
[9]Average unit value obtained from unrounded data.
[10]Measured by sold or used plus imports minus exports.

Phosphate rock inventories declined throughout the year from about 13 million tons to 11 million tons at yearend. Employment in the phosphate rock mining industry was about 5,000. A number of phosphate rock mines in Florida and Idaho were closed for all or part of the year. It is estimated that the phosphate rock industry operated at about 63% of its capacity of 63.2 million tons per year.

Domestic Data Coverage.—Domestic production data for phosphate rock are developed by the Bureau of Mines from two separate voluntary surveys of U.S. operations. Typical of these surveys is the semiannual "Phosphate Rock Survey." Of the 25 operations to which a survey request was sent, all responded, representing 100% of the U.S. production data shown in table 1.

Legislation and Government Programs.—The Corps of Engineers, U.S. Army, completed the Federal improvement to Tampa Harbor, FL, in December 1985 at a cost of $170 million. The main channel from the Gulf of Mexico to East Bay was enlarged to 12.8 meters deep and 152.4 meters wide, with appropriate overdepths and overwidths in the entrance for wave allowance. Branch channels 12.2 meters deep in Port Tampa, Hillsborough Bay Cut D, and Sparkman Channels and 11.6 meters deep in Ybor Channel were being dredged in 1987. Federal maintenance of the Port Sutton terminal channel is scheduled following its enlargement to 12.8 meters deep and 61 meter wide at local cost.

The work was accomplished with the expectation that future exports of phosphate rock from Tampa Bay would follow the pattern developing in 1975. It was forecast that larger tonnages would be hauled by large carriers and lesser amounts in smaller ships. With adequate channel depths, the cargoes would be carried in 40,000- to 85,000-deadweight-ton ships, but a substantial tonnage would still be carried in 20,000- to 40,000-deadweight-ton vessels.

The 1987 session of the Florida Legislature granted the Florida phosphate industry a significant two-phase reduction of the severance tax beginning July 1, 1987. The severance tax in 1986 was $2.51 per ton. The rate was reduced slightly to $2.46 per ton for the January 1, 1987, through June 30, 1987, period. From July 1, 1987, through December 31, 1987, the rate was $1.97 per ton. The rate in 1988 was scheduled to be $1.49 per ton. The severance tax reduction had the effect of reducing phosphate rock production costs in Florida.

An integral part of the budget reconciliation legislation passed by the U.S. Congress in late December was major changes in farm programs. Target prices established by the U.S. Department of Agriculture were reduced from 1987 levels. Paid land diversion for feed grains was reduced from 15% with a payment of $2 per bushel to 10% and a payment of $1.75 per bushel. Caps were placed on paid land diversion programs.

Target prices were established at $4.23 per bushel for wheat, $2.93 per bushel for corn, 75.9 cents per pound for cotton, and $11.50 per hundredweight for rice. To achieve the 2-year budget savings mandated by the Gramm-Rudman-Hollings Deficit Reduction Act, target prices will drop in 1989. The wheat target will drop to $4.10, corn to $2.84, cotton to 73.4 cents, and rice to $10.80.

The U.S. Court of Appeals for the District of Columbia dismissed suits seeking to compel the Secretary of the Interior to issue to the appellants leases to mine phosphate rock in the Osceola National Forest. The judgment of the district court was vacated, and the suits were dismissed as moot. After the appellants filed suit in the district court in 1983, Congress enacted the Florida Wilderness Act in 1984, prohibiting the U.S. Department of the Interior from issuing phosphate leases to mine phosphate rock in the Osceola Forest. On cross-motions the district court held that to demonstrate the discovery of "valuable deposits" of phosphates, the appellants were required to show the economic and technical feasibility of reclaiming lands covered by the lease applications. The court of appeals concluded that the restoration technologies did not exist in 1984 or at any earlier time. The court did not discuss the effect of the Florida Wilderness Act on the litigation or even refer to that statute. The effect of the statute was to make the cause a moot one. The appellants argued that the committee reports on the Florida Wilderness Act were not intended to prejudice or affect any pending legislation. Government agencies assured Congress that the legislation would not prejudice the rights of the lease applicants in any way, and they should be permitted to bring an action in the U.S. Claims Court for compensation for value of the leases.

DOMESTIC PRODUCTION

Production of marketable phosphate rock from Florida and North Carolina increased 6% compared with that of 1986, and production in Tennessee and the Western States decreased 22%. One mining operation was closed in Tennessee, and several mines in Montana and Idaho were closed for part of the year. A number of mines remained closed in Florida.

Florida and North Carolina.—Phosphate rock was produced in central Florida by Agrico Chemical Co., CF Industries Inc., Estech Inc., Gardinier Inc., W. R. Grace & Co., International Minerals & Chemical Corp. (IMC), Mobil Mining and Minerals Co., and USS Agri-Chemicals Inc. In Hamilton County, northern Florida, Occidental Chemical Agricultural Products, Inc., produced phosphate rock.

Manko Co., Howard Phosphate Co., and Loncala Phosphate Co. recovered soft phosphate rock from hard-rock phosphate mine tailing ponds in north-central Florida. The soft rock was sold as an animal feed supplement.

Texasgulf Chemical Co., a subsidiary of Société Nationale Elf Aquitaine, operated the Lee Creek Mine on the Pamlico River in eastern North Carolina. The only organization producing phosphate rock in North Carolina, Texasgulf announced a joint venture with Albright and Wilson Americas to construct a phosphoric acid purification plant at Lee Creek. Texasgulf will supply wet-process phosphoric acid and operate the facility. Albright and Wilson will use the industrial-grade phosphoric acid to produce sodium phosphates in plants in South Carolina and Ohio.

Agrico, a subsidiary of Williams Co. of Tulsa, OK, was sold to Freeport-McMoran Resource Partners Ltd. In Florida, Agrico closed the Saddle Creek Mine in December and reopened the Payne Creek Mine. The Fort Green Mine's operating schedule was changed to balance production.

CF Industries produced phosphate rock from its Hardee Complex Mine. The matrix was mined from the North Pasture deposit. Low domestic demand for phosphate fertilizers restricted operation of the Hardee Complex Mine to one shift per day throughout the year.

Estech operated the Watson Mine, which is two-thirds owned by Zen Noh Phosphate Corp. The Silver City Mine was reopened in late 1986 and was scheduled to produce from the remaining reserve for another 4 years. The Watson Mine will also be depleted in 1991.

The Four Corners Mine, co-owned by W. R. Grace and IMC, had closed in March 1986 and remained closed in 1987. The decision not to reopen the mine in 1988 was confirmed at yearend. W. R. Grace operated the Hookers Prairie Mine in Polk County, FL. In March, W. R. Grace announced that its agricultural chemical business was for sale.

IMC operated the Clear Springs, Kingsford, Noralyn-Phosphoria, and Haynsworth Mines in central Florida. IMC planned to reconstruct the Lonesome Mine and reopen it in the early 1990's or when demand improves to justify additional production.

Mobil purchased the idle Big Four Mine from FCS Energy Inc., in February 1987, only a few days after FCS Energy purchased the mine from AMAX Inc. The Fort Meade Mine operated throughout the year.

Occidental Chemical Co. operated the Suwannee River and Swift Creek Mines north of Lake City, FL. All of the phosphate rock production except for phosphate rock exports was converted into superphosphoric acid at the chemical plants at the respective mines. Occidental has a contract to export up to 700,000 tons per year P_2O_5 as superphosphoric acid to the U.S.S.R.

USS Agri-Chemicals, a division of U.S. Diversified Group, USX Corp., operated the Rockland Mine in a 50-50 partnership with Freeport Chemical Co. The Fort Meade Chemical Products plant, adjacent to the Rockland Mine, is a 50-50 partnership with W. R. Grace. The Bartow Chemical plant, Bartow, FL, is another partnership with W. R. Grace. All of USS Agri-Chemical's assets were for sale.

Tennessee.—Occidental and Stauffer Chemical Co. mined phosphate rock in Giles, Hickman, Maury, and Williamson Counties in south-central Tennessee. The phosphate rock was smelted in electric furnaces to produce elemental phosphorus. Occidental purchased 2,300 acres of Giles County farmland from the Tennessee Valley Authority for their phosphate rock deposits.

Imperial Chemical Industries purchased Stauffer Chemical Co. in June and within several months sold the chemical division of Stauffer to Rhône-Poulenc Inc.

Western States.—Phosphate rock was mined in Idaho, Montana, and Utah. Phosphate rock from Montana was used to manufacture phosphate fertilizer in Canada. Phosphate rock from Idaho was used to

produce fertilizer and elemental phosphorus.

Cominco American Incorporated reactivated the Warm Springs Mine in Montana. The underground mine had been closed since November 1985. A washing, crushing, and drying plant will be moved from Kimberly, British Columbia, Canada, to the Warm Springs Mine. The company, which had previously shipped mine-run ore, planned to upgrade the ore by removing clay in the washer and to ship a sized dry product to Cominco's fertilizer plant at Trail, British Columbia. Full-scale production was scheduled for 1989.

The Conda Partnership was a 50-50 partnership of Beker Phosphate Corp. and Western Cooperative Fertilizers Ltd., Calgary, Alberta, Canada. Nu-West Industries purchased the assets of Beker's phosphate fertilizer plant at Conda, ID, and Beker's 50% interest in the Conda Partnership. The mines and Conda beneficiation plant were closed in May 1986 and reactivated in September 1987.

Chevron Resources Co. mined phosphate rock from the Vernal, UT, mine. After beneficiation, the concentrated slurry was pumped to Rock Springs, WY. Sulfur was supplied to the Rock Springs plant from a large gasfield with high concentration of hydrogen sulfide at Carter Creek, WY. Ammonia was shipped to Rock Springs. The Rock Springs plant was designed to produce 320,000 tons per year of dry fertilizer and 27,000 tons per year of superphosphoric acid.

J. R. Simplot Co. operated the Gay Mine on the Fort Hall Indian Reservation and the Smoky Canyon Mine in the Caribou National Forest. About 80% of the ore from the Gay Mine, a 24% to 26% P_2O_5 shale, was shipped to FMC Corp.'s electric-furnace plant west of Pocatello, ID. The balance of main-bed ore was used by Simplot in its fertilizer plant. Slurried ore from the Smoky Canyon Mine was pumped to Conda, ID. After concentration the product was calcined and shipped by rail to the Pocatello fertilizer plant.

Table 2.—Production of phosphate rock in the United States, by region[1]

(Thousand metric tons and thousand dollars)

Region	Mine production		Marketable production							Ending stocks
			Used directly		Beneficiated		Total[2]			
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Value[3]	
1986[r]	135,683	17,807	3,285	880	37,035	11,388	40,320	12,248	897,131	13,277
1987:										
January-June:										
Florida and North Carolina	68,657	8,163	--	--	17,610	5,387	17,610	5,387	352,825	10,379
Idaho, Montana, Tennessee, and Utah	2,922	702	1,005	265	795	236	1,800	502	28,926	1,450
Total[2]	71,579	8,865	1,005	265	18,406	5,624	19,410	5,889	[4]379,863	11,829
July-December:										
Florida and North Carolina	72,728	9,138	--	--	18,586	5,750	18,586	5,750	363,176	9,337
Idaho, Montana, Tennessee, and Utah	4,119	1,420	1,778	476	1,170	354	2,948	830	49,258	1,547
Total[2]	76,847	10,558	1,778	476	19,766	6,104	21,544	6,580	413,206	10,884
Grand total[2]	148,426	19,423	2,783	741	38,172	11,728	40,954	12,469	[4]793,069	XX

[r]Revised. XX Not applicable.

[1]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.

[2]Data may not add to totals shown because of independent rounding.

[3]Computer-calculated value based on the weighted sold or used value.

[4]The total value is based on a weighted value. The total value does not equal the sum of the regional or 1/2-year totals because weighted regional or overall 1/2-year unit values were used in the calculations. The regional and 1/2-year values are approximate.

CONSUMPTION AND USES

Phosphate rock is the raw material used to manufacture phosphate fertilizers, animal feed phosphates, and elemental phosphorus. Phosphate rock was exported to countries with production facilities for fertilizer, animal feeds, and phosphorus. Phosphate rock was converted into merchant-grade and superphosphoric acid, ammonium phosphates, and superphosphates that were sold domestically or exported. The principal feed phosphate producers, Occidental, Texasgulf, Consolidated Minerals Inc., and IMC, produced for the domestic market. Elemental phosphorus produced in Tennessee, Idaho, and Montana by Occidental, Stauffer, and Monsanto supplied domestic plants that produce a large number of phosphorus chemicals.

Phosphate rock consumption improved 4% in 1987. The increase occurred because of increases in phosphate rock and phosphate fertilizer exports. Domestic demand was restricted by acreage reduction programs and weak export demand for agricultural products. Phosphate rock mined in Florida and North Carolina was consumed in manufacturing fertilizer or animal feeds. The Utah and Montana production was used to produce fertilizer. Phosphate rock produced in Idaho was used to produce fertilizer and elemental phosphorus. All Tennessee phosphate rock was consumed in electric furnaces.

Table 3.—U.S. phosphate rock sold or used grade distribution pattern

Grade (percent BPL[1] content)	Distribution (percent)				
	1983	1984	1985[2]	1986[r]	1987
74 or more	3.0	4.7	2.9	4.5	3.4
72 to less than 74	5.5	2.0	4.2	4.0	5.4
70 to less than 72	8.3	10.1	12.0	7.8	7.1
66 to less than 70	60.6	63.0	62.9	57.5	61.6
60 to less than 66	14.6	8.1	13.1	20.3	17.5
Less than 60	8.0	12.1	4.8	5.9	5.0

[r]Revised.
[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[2]Data do not add to 100% because of independent rounding.

Table 4.—Florida and North Carolina phosphate rock sold or used grade distribution pattern

Grade (percent BPL[1] content)	Distribution (percent)				
	1983	1984	1985[2]	1986	1987
74 or more	3.5	5.4	3.4	5.1	3.8
72 to less than 74	6.4	2.4	4.8	4.6	6.0
70 to less than 72	9.6	9.9	12.6	9.0	7.6
66 to less than 70	64.2	67.5	65.9	60.7	65.3
60 to less than 66	13.0	7.0	12.8	20.6	17.3
Less than 60	3.3	7.8	.6	--	([3])

[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[2]Data do not add to 100% because of independent rounding.
[3]Less than 0.1 of 1%.

Table 5.—Tennessee and Western States phosphate rock sold or used grade distribution pattern

Grade (percent BPL[1] content)	Distribution (percent)				
	1983[2]	1984[2]	1985[2]	1986[r]	1987
70 to less than 72	NA	NA	NA	--	3.6
66 to less than 70	NA	NA	NA	36.1	33.9
60 to less than 66	NA	NA	NA	18.5	19.3
Less than 60	NA	NA	NA	45.4	43.3

[r]Revised. NA Not available.
[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[2]Data for Tennessee and Western States (Idaho, Montana, and Utah) were reported separately in the 1985 and 1986 Minerals Yearbook chapter.

Table 6.—Phosphate rock sold or used by producers in the United States, by grade and region[1]

(Thousand metric tons and thousand dollars)

Grade (percent BPL[2] content)	Florida and North Carolina			Tennessee and Western States[3]			Total		
	Rock	P_2O_5 content	Value[4 5]	Rock	P_2O_5 content	Value[4 5]	Rock	P_2O_5 content	Value[4 5]
January-June 1986[r]	17,665	5,466	398,067	2,776	780	68,006	20,441	6,246	466,073
July-December 1986[r]	18,668	5,769	412,362	2,669	735	51,187	21,337	6,504	463,549
January-June 1987:									
74 or more	410	142	11,850	--	--	--	410	142	11,850
72 to less than 74	1,719	579	39,269	--	--	--	1,719	579	39,269
70 to less than 72	1,216	394	27,933	--	--	--	1,216	394	27,933
66 to less than 70	11,912	3,679	228,190	828	257	19,331	12,740	3,937	247,521
60 to less than 66	3,753	1,054	73,474	470	129	4,664	4,224	1,182	78,138
Below 60	17	4	372	838	226	10,049	905	231	10,421
Total[6]	19,027	5,851	381,088	2,186	613	34,044	21,214	6,465	415,132
July-December 1987:									
74 or more	1,071	368	25,244	--	--	--	1,071	368	25,244
72 to less than 74	624	208	13,428	--	--	--	624	208	13,428
70 to less than 72	1,707	554	42,848	173	57	6,095	1,880	611	48,943
66 to less than 70	13,337	4,107	248,167	859	266	20,271	14,196	4,373	268,438
60 to less than 66	2,925	801	54,285	493	137	5,639	3,418	938	59,924
Below 60	--	--	--	1,270	323	14,703	1,270	323	14,703
Total[6]	19,664	6,039	383,972	2,795	783	46,708	22,459	6,821	430,680

[r]Revised.
[1]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.
[2]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[3]Includes Idaho, Montana, and Utah.
[4]F.o.b. mine.
[5]The total value is based on a weighted value. The total value does not equal the sum of the regional totals because weighted regional unit values were used in the calculations. The regional values are approximate.
[6]Data may not add to totals shown because of independent rounding.

Table 7.—Phosphate rock sold or used by producers in the United States, by use[1]

(Thousand metric tons)

Use	1986 total		1987					
			January-June		July-December		Total[2]	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
Domestic:[3]								
Wet-process phosphoric acid	27,979	8,512	15,017	4,538	15,852	4,791	30,868	9,329
Normal superphosphate	210	66	36	12	15	5	50	16
Triple superphosphate	1,292	436	422	141	505	162	927	303
Defluorinated rock	78	27	111	38	75	26	186	65
Direct applications	1,032	325	--	--	9	3	9	3
Elemental phosphorus	r3,177	r822	1,317	347	1,696	444	3,013	791
Ferrophosphorus	r162	r40	75	19	91	23	166	42
Total[2]	r33,930	r10,228	16,978	5,095	18,242	5,454	35,219	10,549
Exports[4]	7,848	2,521	4,237	1,369	4,217	1,368	8,454	2,737
Grand total[2]	r41,778	r12,751	21,214	6,464	22,458	6,821	43,673	13,286

rRevised.
[1]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes rock converted to products and exported.
[4]Exports reported to the Bureau of Mines by companies.

Table 8.—Phosphate rock sold or used by producers in the United States, by use and region[1]

(Thousand metric tons)

Use	Florida and North Carolina		Tennessee and Western States[2]		Total[3]	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
1986r	36,333	11,236	5,443	1,515	41,776	12,750
1987:						
January-June:						
Domestic:[4]						
Agricultural	14,854	4,503	731	227	15,586	4,730
Industrial	34	10	1,358	356	1,392	366
Total	14,888	4,513	2,089	583	16,978	5,096
Exports[5]	4,140	1,339	97	30	4,237	1,369
Total[3]	19,028	5,852	2,186	613	21,215	6,465
July-December:						
Domestic:[4]						
Agricultural	15,487	4,685	968	302	16,455	4,987
Industrial	24	7	1,763	460	1,787	467
Total	15,511	4,692	2,731	762	18,242	5,454
Exports[5]	4,153	1,348	64	20	4,217	1,368
Total[3]	19,664	6,040	2,795	782	22,459	6,822
Grand total[3]	38,692	11,892	4,981	1,395	43,674	13,287

rRevised.
[1]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.
[2]Includes Idaho, Montana, and Utah.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes rock converted to products and exported.
[5]Exports reported to the Bureau of Mines by companies.

Table 9.—Florida and North Carolina phosphate rock sold or used by producers[1]

Year	Rock (thousand metric tons)	P_2O_5 content (thousand metric tons)	Value	
			Total[2] (thousands)	Average per ton f.o.b. mine
1983	40,225	12,456	$944,509	$23.48
1984	46,411	14,309	1,089,647	23.48
1985	40,857	12,702	972,748	23.81
1986	36,333	11,236	810,429	22.31
1987	38,092	11,891	765,061	19.77

[1]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.
[2]The total value is based on a weighted value.

Table 10.—Tennessee and Western States[1] phosphate rock sold or used by producers[2]

Year	Rock (thousand metric tons)	P_2O_5 content (thousand metric tons)	Value	
			Total[3] (thousands)	Average per ton f.o.b. mine
1983[4]	NA	NA	NA	NA
1984[4]	NA	NA	NA	NA
1985[4]	NA	NA	NA	NA
1986[r]	5,443	1,515	$119,192	$21.90
1987	4,981	1,395	80,751	16.21

[r]Revised. NA Not available.
[1]Includes Idaho, Montana, and Utah.
[2]Data for the same items appearing in this and other tables may not reconcile because of computer rounding.
[3]The total value is based on a weighted value.
[4]Data for Tennessee and Western States were reported separately in the 1985 and 1986 Minerals Yearbook chapter.

Table 11.—Marketable phosphate rock yearend stocks

(Million metric tons)

Year	Quantity
1978	15.7
1979	14.5
1980	13.7
1981	19.6
1982	18.3
1983	14.5
1984	11.9
1985	15.5
1986	[r]13.3
1987	10.9

[r]Revised.

PRICES

Phosphate rock was sold under contracts negotiated between buyers and sellers. Although list selling prices were occasionally published by producing organizations, actual negotiated prices were not published.

Phosphate rock export prices from Tampa and Jacksonville, FL, included freight, loading, and weighing costs of $6.17 and $9.30, respectively. The severance tax, included in the export price, was $2.46 per ton for the first half of the year and $1.97 per ton in the second half.

The weighted averaged prices or values, f.o.b. mine, for each grade of phosphate rock and for each producing region were calculated and published by the Bureau of Mines from the semiannual survey of producers.

Table 12.—Phosphate rock estimated export prices[1] per metric ton, unground, f.o.b. vessel Tampa Range or Jacksonville, FL, by grade

Grade (percent BPL[2] content)	1984[3]	1985[4]	1986[5]	1987[6]
75	$35.00	$34.00	$33.00	$32.00
72	30.50	30.50	31.00	29.00
70	27.50	28.00	27.00	27.50
68	26.50	26.00	25.50	24.00

[1]Prices include severance taxes, rail freight costs from mine to port, and port loading and weighing charges.
[2]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[3]Estimated selling price including $2.39 severance tax.
[4]Estimated selling price including $2.52 severance tax.
[5]Estimated selling price including $2.51 severance tax.
[6]Estimated selling price including $2.46 severance tax.

Table 13.—Moroccan phosphate rock export prices, U.S. dollars per metric ton, f.a.s. Safi or Casablanca,[e] by grade

Grade (percent BPL[1] content)	1984	1985	1986	1987
Khouribga:				
76 to 77	47.00	47.00	45.00	42.00
70 to 71	36.00	36.00	35.00	34.00
Youssoufia:				
74 to 75	43.00	43.00	40.50	39.50
68 to 69	30.00	30.00	30.50	30.00

[e]Estimated.
[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

Table 14.—Price or value of Florida and North Carolina phosphate rock, by grade

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[1] content)	1986			1987		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	28.87	35.05	31.32	26.73	24.48	25.05
72 to less than 74	18.93	24.67	22.43	19.90	23.68	22.49
70 to less than 72	18.80	25.18	24.38	23.64	24.26	24.21
66 to less than 70	20.32	22.15	20.50	18.62	21.06	18.87
60 to less than 66	24.63	21.53	24.47	19.26	17.10	19.13
Less than 60	--	--	--	21.66	--	21.66
Average	21.64	25.02	22.31	18.93	22.87	19.77

[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

Table 15.—Price or value of Tennessee and Western States[1] phosphate rock, by grade

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[2] content)	1986			1987		
	Domestic	Export	Average	Domestic	Export	Average
70 to less than 72	--	--	--	35.27	--	35.27
66 to less than 70	r28.36	47.87	r32.61	22.62	31.50	23.47
60 to less than 66	10.04	41.69	16.11	10.70	--	10.70
Less than 60	r14.93	--	r14.93	11.47	--	11.47
Average	r18.18	46.21	r21.90	15.70	31.50	16.21

rRevised.
[1]Includes Idaho, Montana, and Utah.
[2]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

Table 16.—Price or value of U.S. phosphate rock, by grade

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[1] content)	1986			1987		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	28.87	35.05	31.32	26.73	24.48	25.05
72 to less than 74	18.93	24.67	22.43	19.90	23.68	22.49
70 to less than 72	18.80	25.18	24.38	28.32	24.26	24.83
66 to less than 70	r20.86	27.26	r21.57	18.88	21.69	19.15
60 to less than 66	23.13	28.23	23.48	18.12	17.10	18.07
Less than 60	r14.93	--	r14.93	11.55	--	11.55
Average	r21.16	26.97	r22.25	18.49	23.03	19.37

rRevised.
[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

FOREIGN TRADE

Export tonnage of phosphate rock was 8% higher than that of 1986, although it did not exceed the average of the past 7 years. The increase in export sales was due primarily to competitive prices offered by U.S. exporters. Phosphate rock was again in oversupply in 1987, causing downward pressure on prices.

Phosphate rock imports for consumption decreased in 1987. The principal countries exporting to the United States were Togo and Morocco. Lesser tonnages were imported from the Federal Republic of Germany, the Netherlands Antilles, the United Kingdom, and miscellaneous sources.

Table 17.—U.S. exports of phosphate rock, by country

(Thousand metric tons and thousand dollars)

(Schedule B No. 480.4500)

Country	1986		1987	
	Quantity[1]	Value	Quantity[1]	Value
Australia	112		52	
Austria	45		34	
Belgium-Luxembourg	449		317	
Brazil	43		9	
Canada	2,351		1,384	
Finland	91		64	
France	787		699	
Germany, Federal Republic of	595		532	
India	278		344	
Italy	95		394	
Japan	986	NA	1,036	NA
Korea, Republic of	1,374		1,344	
Mexico	278		412	
Netherlands	51		668	
New Zealand	67		162	
Philippines	32			
Poland	521		604	
Romania	91		150	
Sweden	82		98	
United Kingdom	1			
Other	927		322	
Total[2]	9,176	211,701	8,685	194,691

NA Not available.

[1]Individual country exports furnished by Bureau of the Census will not add to totals.

[2]Total quantity and value reported to the Bureau of Mines, f.o.b. mine.

Table 18.—U.S. exports of superphosphates, more than 40% P_2O_5, by country

(Thousand metric tons and thousand dollars)

(Schedule B No. 480.7050)

Country	1986		1987	
	Quantity	Value[1]	Quantity	Value[1]
Argentina	10		11	
Australia	60		79	
Belgium-Luxembourg	43		30	
Brazil	207		172	
Bulgaria	46		23	
Burma	16		15	
Canada	277		434	
Chile	129		170	
Colombia	12		21	
Costa Rica	10	NA	6	NA
Czechoslovakia	118		26	
Dominican Republic	13		11	
France	--		3	
Germany, Federal Republic of	10		--	
Ireland	30		--	
Japan	38		60	
Mexico	122		24	
Peru	28		15	
Spain	18		--	

See footnotes at end of table.

Table 18.—U.S. exports of superphosphates, more than 40% P_2O_5, by country —Continued

(Schedule B No. 480.7050)

Country	1986		1987	
	Quantity	Value[1]	Quantity	Value[1]
Uruguay	15	NA	14	NA
Other	31		46	
Total	1,283	155,774	1,160	192,308

NA Not available.
[1]All values f.a.s. (free alongside ship).

Source: Bureau of the Census.

Table 19.—U.S. exports of superphosphates, less than 40% P_2O_5, by country

(Schedule B No. 480.7030)

Country	1986		1987	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	3,990	$87	2,404	NA
Other	--	--	376	NA
Total	3,990	87	2,780	$94

NA Not available.
[1]All values f.a.s. (free alongside ship).

Source: Bureau of the Census.

Table 20.—U.S. exports of diammonium phosphates, by country

(Thousand metric tons and thousand dollars)

(Schedule B No. 480.8006)

Country	1986		1987	
	Quantity	Value[1]	Quantity	Value[1]
Argentina	106	NA	72	NA
Australia	190		181	
Belgium-Luxembourg	353		594	
Brazil	173		101	
Canada	117		162	
Chile	67		71	
China	542		1,441	
Colombia	91		133	
Costa Rica	17		22	
Dominican Republic	25		43	
Ecuador	28		30	
France	26		146	
Germany, Federal Republic of	17		137	
Guatemala	25		13	
India	441		--	
Iran	--		116	
Ireland	17		54	
Italy	196		326	
Japan	162		343	
Kenya	--		80	
Mexico	88		39	
New Zealand	24		34	
Pakistan	607		32	
Peru	--		48	
Spain	--		163	
Thailand	9		32	
Turkey	286		44	
Uruguay	32		37	
Venezuela	--		224	
Yugoslavia	24		55	
Other	462		874	
Total	4,120	641,385	5,547	890,801

NA Not available.
[1]All values f.a.s. (free alongside ship).

Source: Bureau of the Census.

Table 21.—U.S. exports of phosphoric acid, less than 65% P_2O_5, by country

(Thousand metric tons and thousand dollars)

(Schedule B No. 480.7015)

Country	1986		1987	
	Quantity	Value[1]	Quantity	Value[1]
Australia	--	NA	61	NA
Canada	2		2	
Colombia	9		3	
India	273		179	
Indonesia	46		65	
Japan	--		58	
Venezuela	106		79	
Other	264		53	
Total	700	110,010	500	85,912

NA Not available.
[1]All values f.a.s. (free alongside ship).

Source: Bureau of the Census.

Table 22.—U.S. exports of elemental phosphorus, by country

(Schedule B No. 415.3500)

Country	1986		1987	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Brazil	6,557	NA	5,621	$10,368
Canada	487		139	210
Japan	8,436		6,170	9,339
Korea, Republic of	402		1,277	1,715
Mexico	2,802		6,481	8,424
Taiwan	1,424		84	103
Other	148		536	637
Total	20,266	$33,310	20,302	30,796

NA Not available.
[1]All values f.a.s. (free alongside ship).

Source: Bureau of the Census.

Table 23.—U.S. imports for consumption of phosphate rock and phosphatic materials

(Thousand metric tons and thousand dollars)

Fertilizer	TSUS No.[1]	1986		1987	
		Quantity	Value[2]	Quantity	Value[2]
Phosphates, crude and apatite[3]	480.4500	528	22,265	464	18,816
Phosphatic fertilizers and fertilizer materials	480.7070-480.8095	69	8,351	55	7,820
Dicalcium phosphate	418.2800	1,420	1,209	1,960	2,086
Phosphorus	415.3500	1,510	3,548	4,463	6,609
Phosphoric acid, technical-grade	480.7010	(4)	157	1	1,667
Normal superphosphate	480.7030	1	294	3	585
Triple superphosphate	480.7050	1	112	49	6,262

[1]Tariff Schedules of the United States.
[2]Declared customs valuation.
[3]Excludes reported imports from Canada and Israel.
[4]Less than 1/2 unit.

Source: Bureau of the Census.

WORLD REVIEW

Phosphate rock production exceeded world demand. Oversupply of phosphate rock in world markets sharpened competition; prices declined, and profit margins disappeared. Numerous phosphate rock mines were closed or operating schedules were reduced to balance demand and prevent inventories from rising.

Demand for phosphate fertilizers declined substantially as food supplies increased throughout the world. The oversupply of agricultural commodities drastically reduced demand for phosphate fertilizers. Acreage reduction programs in the United States, designed to reduce farm commodity surpluses, and similar programs in Western Europe and Japan were extended through 1987 in an attempt to manage agricultural production, reduce inventories, and improve the farm economy.

Plans to develop new phosphate rock mines or expand existing mines were deferred or canceled by governments and companies. It is probable that the phosphate rock industry will, under pressure from lower prices, have to wait until supply and demand are in balance before new projects and ventures are implemented.

The phosphate rock tabulation in table 24 was developed with the assistance of the International Fertilizer Industry Association Ltd., Paris, France.

Australia.—In Western Australia, Union Oil sold its 60% interest in the Mount Weld phosphate deposit, near Laverton, to CSBP & Farmers. The Broken Hill Pty. Ltd. (BHP)

retained its 40% interest. About 7,500 tons of phosphate rock was mined. It was unsuitable for the manufacture of superphosphates but was used in organic horticultural fertilizer products. Queensland Phosphate Pty. Ltd. produced 26,813 tons from the Duchess Mine in a campaign operation. The mine was in a care and maintenance condition for the balance of the year.[3]

China.—The State Statistical Bureau, Beijing, reported that phosphate fertilizer production peaked at 2,666,000 tons in 1983 and declined in successive years to 1,760,000 tons in 1985.

Christmas Island.—The Australian Government closed the phosphate rock mines on Christmas Island after production declined in 1986, and the rate of production continued downward in 1987.[4]

Egypt.—A new beneficiation plant for the El Nasrab phosphate rock mine was scheduled to start operating in early 1988. Prior to construction of the new plant, the phosphate rock was hand-sorted and crushed. The new plant will process up to 1.2 million tons per year using two production lines.[5]

Iraq.—The Government of Iraq announced the discovery of 3,500 million tons of phosphate rock reserves at the Akashat Mine.[6]

Jordan.—Jordan Phosphate Mines Co. planned to produce 800,000 tons of phosphate rock from the Eshidiya Mine in 1988. The Rusaifa Mine, closed in 1985, remained inactive. Production in 1987 was restricted to the El Abiad and El Hassa Mines.

Mexico.—The fertilizer project at Lazaro Cardenas on the Pacific coast was commissioned. The first-phase 50-LAC project and part of the second-phase 93-LAC project were completed in 1986; however, the triple superphosphate plant of 93-LAC was not completed until 1987.[7]

Morocco.—The Moroccan Office Cherifien des Phosphates announced plans to increase the phosphoric acid capacity at Jorf Lasfar by adding to Maroc Phosphore. The new plants will double the capacity of Jorf Lasfar. A new mine on the Oulad Abdoun Plateau, part of the Khouribga District, will gradually replace the Sidi Daoui Mine as it is depleted. The new mine, Sidi Chennane, is scheduled to start producing in 1990 and will supply dried phosphate rock to Jorf Lasfar.

Senegal.—Industries Chemiques du Senegal (ICS) is a chemical complex adjacent to the Taiba phosphate mines at Darow-Khoudoss, 90 kilometers northeast of Dakar. The plant has gradually increased production since its inception. The sulfuric acid plant has a capacity of 560,000 tons per year, and the phosphoric acid plant was rated at 220,000 tons per year. Triple superphosphates and diammonium phosphates are produced in the Dakar suburbs for the export market.[8]

Syria.—Gecopham, a Government-owned company, produced phosphate rock from two mines in the Kneifiss and the eastern areas of the Ghardiral Hamal region of the Palmrides. Gecopham added mining machinery in the phosphate mines and expanded the export facilities at Tartous from 1.3 million tons per year to 2.4 million tons per year to be able to supply additional phosphate rock if sales improve.[9]

Tunisia.—The Government authorized the development of the Kef Eddour phosphate mine near Gafsa to produce phosphate rock for a new phosphoric acid plant at La Skirrah, which was due on-stream in 1987. The phosphoric acid plant will use phosphate rock from the Gafsa District until the 1.4-million-ton-per-year Kef Eddour Mine is completed.[10]

U.S.S.R.—The Soviet Union awarded a contract to Outokumpu Oy, Finland's state-owned mining company, to construct a new flotation plant on the Kola Peninsula. The beneficiation plant's first stage was completed in 1985 with a capacity of 1.3 million tons per year.[11]

Table 24.—Phosphate rock, basic slag, and guano: World production, by country[1]

(Thousand metric tons)

Commodity and country[2]	Gross weight					P_2O_5 content				
	1983	1984	1985	1986[p]	1987[e]	1983	1984	1985	1986[p]	1987[e]
Phosphate rock:										
Algeria	893	e1,000	1,207	1,208	1,073	276	309	e381	e380	336
Australia	5	15	33	84	10	1	4	7	7	2
Brazil	3,208	3,855	4,214	4,509	4,777	1,119	1,345	1,475	1,620	1,694
Chile	1	5	7	7	7	(3)	(3)	1	1	1
China[e]	12,500	11,800	6,970	6,700	9,000	3,375	3,186	1,882	r1,810	2,700
Christmas Island (Indian Ocean)	1,094	1,259	1,187	880	e842	385	443	418	310	296
Colombia	17	11	24	27	34	3	2	5	e6	8
Egypt	647	1,043	e1,074	1,271	1,083	205	253	270	315	312
Finland	381	477	512	527	558	141	176	189	195	195
India	658	892	929	659	750	212	294	307	219	234
Indonesia	6	2	1	1	3	2	1	1	1	1
Iraq[e]	1,199	1,000	1,000	1,000	1,500	261	218	218	218	280
Israel	2,969	3,312	4,076	3,673	e3,798	892	995	1,210	1,110	1,214
Jordan	4,749	6,263	6,067	6,249	6,801	1,548	2,042	2,010	2,072	2,254
Korea, North[e]	500	500	500	500	500	160	160	160	160	160
Mexico[e]	389	375	550	600	640	117	113	166	e180	197
Morocco[e]	20,106	21,245	20,737	21,178	20,955	e5,400	e6,762	e6,574	e6,714	6,650
Nauru	1,684	1,358	1,508	1,494	e1,376	648	523	e581	e575	530
Pakistan	--	--	--	50	e32	--	--	--	16	e10
Peru	3	13	12	30	90	1	4	r e4	r e9	27
Philippines	4	7	6	e5	8	1	2	2	e2	2
Senegal	1,521	1,912	1,814	1,850	1,880	534	583	e617	e641	680
South Africa, Republic of	2,887	2,585	2,433	2,920	2,623	e996	e939	e883	e1,060	950
Sri Lanka	16	14	14	15	21	6	5	5	5	7
Sweden	107	133	187	192	221	41	51	74	72	82
Syria	1,229	1,514	e1,270	e1,606	1,986	375	461	380	485	606
Tanzania	20	15	e15	e10	18	6	4	e4	e3	4
Thailand	5	3	4	5	4	1	1	1	1	1
Togo	2,081	2,696	2,452	2,314	e2,644	755	979	890	840	960
Tunisia	5,924	5,346	4,530	5,951	6,390	1,700	1,554	e1,303	e1,712	1,836
Turkey	50	96	e37	3	19	15	29	e12	e1	6
U.S.S.R.[e]	r33,100	r33,300	r33,750	r33,900	34,100	r10,350	r10,550	r10,650	r10,700	10,750
United States	42,573	49,197	50,835	38,710	e40,954	13,088	14,889	15,674	11,857	12,491
Vietnam[e]	200	200	r516	r530	300	66	66	r170	r175	105
Zimbabwe	133	125	135	136	156	47	44	48	48	55
Total	r140,889	r151,568	148,606	138,740	145,148	r43,728	r46,987	46,558	43,509	45,735

Basic (Thomas converter) slag:										
Argentina	1	1	e1	e1	1	(3)	(3)	(3)	(3)	(3)
Belgium	250	254	143	r e150	175	45	46	26	r e27	32
Egypt[e]	e10	e10	10	8	8	2	2	2	2	2
France	1,124	1,194	1,165	855	1,000	202	215	210	154	180
Germany, Federal Republic of	409	446	491	374	370	93	62	67	55	50
Luxembourg	586	728	701	e650	700	105	131	126	e117	126
United Kingdom	4	4	e4	--	--	1	1	e1	--	--
Total	2,384	2,637	2,515	2,038	2,254	448	r437	432	355	390
Guano:										
Chile	(3)	3	3	3	7	(3)	(3)	(3)	1	1
Kenya	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
Philippines	1	1	1	e1	1	(3)	(3)	(3)	e(3)	(3)
Seychelles Islands (exports)[e]	5	5	5	5	5	e2	e2	2	2	2
Total	6	r9	9	14	13	2	2	2	3	3

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through May 13, 1968. Data for major phosphate-rock-producing countries derived in part from the International Fertilizer Industry Association; other figures are from official country sources where available.

[2]In addition to the countries listed, Belgium and Uganda may have produced small quantities of phosphate rock, and Namibia may have produced small quantities of guano, but output is not officially reported, and available information is inadequate for formulation of reliable estimates of output levels.

[3]Less than 1/2 unit.

[4]Reported figure.

[5]Includes only output used to manufacture fertilizers.

[6]Production from Western Sahara area included with Morocco.

TECHNOLOGY

The declining quality of phosphate rock reserves has promoted the development of processes to reduce the levels of impurities in marketable phosphate rock. Impurities collected in phosphoric acid cause problems in processing the acid and with the quality of downstream products. In some instances it is possible to beneficiate the phosphate ore or matrix by physically separating a size fraction that contains the impurity. If the impurity is part of the chemical structure of the mineral and cannot be liberated by size reduction, the ore will not respond to the treatment. In addition to classification, it is usually necessary to employ flotation if the mixture of ore and gangue is of a similar size. A flotation circuit is commonly used to separate phosphate minerals from a silicate gangue and reduce carbonate to an acceptable level. The flotation feed is treated with reagents to cause the surfaces of different minerals to be attracted to air or water, permitting one or more to be floated or depressed in the mixture of water and air bubbles.

Société Industrielle d'Acide Phosphorique et d'Engrais (SIAPE) installed a 13,000-ton-per-year P_2O_5 demonstration plant to reduce magnesium oxide in phosphoric acid. The plant, which used a folded-bed chemical separation process, was constructed and commissioned in Sfax, Tunisia, in 1986. An ion-exchange section removes magnesium, and the resin is regenerated with sulfuric acid. Magnesium oxide was reduced from 0.55% to 0.65% to 0.04% to 0.1% levels.[12]

Negev Phosphates Ltd., developed a proprietary flotation reagent that can separate phosphate-bearing minerals from calcium carbonate. This process replaces a washing and classification flowsheet that separates a middle-size-fraction from phosphate-poor coarse and fine fractions. The flotation process improved grade and recovery. The flotation process was used at the Tamar facility, recovering phosphate rock from a fine waste tailing.[13]

Highly reactive, finely ground phosphate rock can be used as a fertilizer where the soils, particularly soils in the tropics, are deficient in phosphorus. If the indigenous phosphate rock is unsuitable for dried application, a partially acidulated phosphate rock may perform well, and the crop response may be similar to that of soil treated with conventional single or triple superphosphate. A partially acidulated phosphate rock (PAPR) is one that is acidulated with less than the stoichiometric quantity of sulfuric or phosphoric acid to achieve complete solubility. The amount of water-soluble phosphate in a PAPR will vary with the degree of acidulation.

Run-of-pile PAPR is produced by continuously mixing ground phosphate rock and sulfuric acid in a pugmill or similar mill. The mixed product may be transferred to storage.

The single-step acidulation-granulation process mixes phosphate rock, acid, and water plus recycled material in a rotary drum granulator. The product is dried, screened, and crushed if necessary to obtain a sized product.[14]

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[1]Physical scientist, Branch of Industrial Minerals.
[2]All quantities are in metric tons unless otherwise specified.
[3]U.S. Embassy, Canberra, Australia. State Dep. Airgram, Apr. 8, 1987, 1 p.
[4]Fertilizer Week. No. 35, Jan. 11, 1988, p. 4.
[5]Fertilizer International. No. 236, Oct. 9, 1986, p. 6.
[6]Mining Annual Review. June 1987, pp. 454-455.
[7]Fertilizer International. No. 237, Oct. 23, 1986.
[8]Page 427 of work cited in footnote 6.
[9]Pages 449-450 of work cited in footnote 6.
[10]U.S. Embassy, Tunis, Tunisia. State Dep. Airgram 01579, Feb. 19, 1988, 2 pp.
[11]Engineering and Mining Journal. No. 147, Jan. 1987, p. 14.
[12]Phosphorus & Potassium. No. 148, Mar.-Apr. 1987, pp. 35-40.
[13]———. No. 147, Jan.-Feb. 1987, p. 37.
[14]———. No. 150, July-Aug. 1987, pp. 48-53.

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